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## OCCULTATION STUDIES OF THE SOLAR SYSTEM

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## INTRODUCTION

The planetary occultation program began at Lowell Observatory in 1973 when Brinkmann and Millis (1973) coordinated a worldwide campaign to observe mutual occultations and eclipses of the Galilean Satellites. Subsequently the temperature structure of the Martian atmosphere was measured from data taken during the occultation of  $\epsilon$  Geminorum (Wasserman, Millis, and Williamon 1977); the Rings of Uranus were discovered as they occulted SAO 158687 (Millis, Wasserman, and Birch 1977); and the dimensions of Pallas were measured when that minor planet occulted SAO 85009 (Wasserman *et al.* 1979). In 1979 the present grant was initiated and has supported our occultation research since that time. The grant provided funds for portable photometric instrumentation which we have used to observe occultations by asteroids as well as occultations by Uranus and Neptune (e.g., Millis *et al.* 1981, 1983, 1984 and 1985). Software for predicting occultations of catalog stars by asteroids, planets, and comets was written in 1983. We currently provide most of the available predictions for asteroid occultations (Wasserman, Bowell, and Millis 1983 and 1985). Realizing in 1983 that the lack of a high-quality astrometric telescope dedicated to occultation work was limiting progress in this field, we acquired an 18-inch, F/8 lens and adapted it to an existing mounting at Lowell. Although acquisition of the lens and implementation of the new telescope has been accomplished primarily with non-grant funds, the instrument is making a major contribution to this research.

Occultation research is inherently an opportunistic endeavor. We attempt to take an integrated approach in our program with attention to long-range identification of upcoming opportunities, intensive prediction refinement efforts for important events, and, most importantly, observation of occultations using portable or fixed telescopes around the world. The focus of our research will necessarily shift from year to year depending on what occultations are available. In the past year, we have concentrated on analysis of existing observations and on bringing the astrograph to its full potential. Few attractive occultations occurred in the United States. Only one occultation expedition was launched by our group during the year, and it was unsuccessful because of poor weather. In 1987 the observational side of our program will pick up as we bring the astrograph into full use and pursue the asteroid and Pluto occultations that have already been identified.

## ACCOMPLISHMENTS OF THE PAST SIX MONTHS

Two and a half years ago we observed an occultation of a star by Ceres using portable gear along the west coast of Mexico. This occultation was also observed by colleagues at the University of Arizona, the Massachusetts Institute of Technology, the Florida Institute of Technology, the University of Maryland, and others. The analysis of the total data set from this occultation was undertaken by our group and turned out to be a lengthy study. Inconsistencies in the various data sets had to be resolved and multitudinous collaborators consulted as the investigation

progressed. Only within the last few weeks was the job completed and the resulting paper accepted for publication in *Icarus* (Millis *et al.* 1987). We believe that the results justify the investment of our time. The dimensions of Ceres were determined with an uncertainty of only about 2%, the bulk density of the asteroid computed to within 5%, and its shape shown to be that of an object in hydrostatic equilibrium.

In 1982 Millis observed an occultation of a star by Uranus and the Rings with the 1.5-meter Infrared Flux Collector at Teide Observatory in the Canary Islands. During the reporting period, Millis and Wasserman in collaboration with Richard French of MIT completed an analysis of those data. The results of that study were recently published in *Icarus* (Millis, Wasserman, and French 1987). Using Elliot *et al.*'s (1984) square-well model, midtimes, widths, and optical depths of the individual rings were determined. Because this occultation was observed "simultaneously" from Chile, Pic du Midi, and the Canary Islands, the data helped provide strong constraints on ring orbital elements. It was also possible from our data to derive the atmospheric temperature profile for the planet.

A review paper by Millis (1986) entitled "Occultation Studies with Small Telescopes" was recently published. Also appearing in 1986 was the abstract of a paper discussing the results from an occultation by Antigone (Wasserman, Millis, and Franz 1986).

Franz and Nye have devoted much effort in the past year to understanding and improving the performance of the 18-inch astrograph. A new right ascension drive was installed, and high-quality glass filters were obtained to replace the inferior gelatin and plexiglass filters used in the past. It is now possible to take well-guided exposures in which the filter does not limit the attainable astrometric accuracy. The telescope has been used regularly since the fall of 1986 and is being routinely applied to occultation prediction work. The results are encouraging. In mid-January 1987 an occultation by Hygiea was observed at Table Mountain Observatory (Harris 1987). Prediction refinement for that event was done entirely with our telescope. As we continue to improve the 18-inch astrograph and refine our plate reduction procedures, we expect that this telescope will play an increasing role in the progress of occultation research. Already plates have been taken to extend Mink and Klemola's (1985) predictions for Pluto occultations to fainter magnitude limits. Photometry by Bosh *et al.* (1986) has shown that all of the stars identified by Mink and Klemola are significantly brighter than required to give an occultation with an adequate signal-to-noise ratio. We have taken plates covering Pluto's path in the sky during 1987 and 1988. These plates were scanned by Anita Killian of MIT, and many potential occultation candidates missing from Mink and Klemola's list were found.

During 1986, Millis, in his role as Chairman, orchestrated a reorganization of the IAU Commission 20 Working Group on Occultations. Regional coordinators have been recruited who are responsible for funneling information to observers in

their areas. Additionally, 16 occultations occurring in 1987 have been targeted for special attention. The Lowell and Lick astrographs are being used to provide refined predictions for these events. Of the three events that have occurred so far this year, one was successfully observed. The track of one of the other two moved off the Earth, while that of the third drifted south into Central America, where few observers are available. We expect that by concentrating prediction efforts on a limited number of occultations, the observational success rate will be improved.

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#### BUDGET

Expenditures during the reporting period under this grant were closely in line with the proposal budget.